PREVENTION OF OVERT MOTION SICKNESS BY INCREMENTAL EXPOSURE TO OTHERWISE HIGHLY STRESSFUL CORIOLIS ACCELERATIONS*

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SUMMARY PAGE

THE PROBLEM

In previous experiments normal subjects suddenly exposed to a terminal velocity of 10 rpm in a slow rotation room (SRR) invariably became motion sick while carrying out routine tasks whereas, under the same conditions, persons with bilateral labyrinthine defects did not. The symptoms resulted from Coriolis accelerations generated by movements of the head out of the plane of the room's rotation, and the term "SRR sickness" was suggested to identify the etiologic force environment.

FINDINGS

In the present experiment overt symptoms of motion sickness at 10 rpm were prevented solely by means of incremental increases to terminal velocity. This demonstrated that the adaptive processes somehow inhibited the irradiation of vestibular activity to cell assemblies in cerebellar, hypothalamic, and other areas concerned in the genesis of symptoms and that "habituation of symptoms" was not essential in their prevention. By ensuring man's stability, these processes properly may be regarded as homeostatic in nature, preserving a homeostatic state. This implies that SRR sickness may be defined as a failure in homeostatic processes caused by too sudden an exposure to strong Coriolis acceleration which somehow permitted irradiation of vestibular activity to areas either not normally stimulated or stimulated below the level of subjective awareness. The symptoms of such sickness represent absurd responses in terms of man's welfare leading to instability. The underlying processes therefore are clearly nonhomeostatic in nature, producing a nonhomeostatic state. The findings in the present experiment have practical as well as theoretical implications.

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INTRODUCTION

In a slowly rotating room the stressful Coriolis accelerations resulting in motion sickness are generated by rotation of the head out of the plane of the room's rotation. In contrast to field studies in turbulent air or on turbulent seas, the stressful stimuli can be precisely controlled in a laboratory setting. The subject fixating his head in the room can abolish the stressful accelerations; the experimenter can exercise control either by varying the velocity of the room's rotation or by regulating the subject's head movements (7).

In previous experiments the essentiality of the vestibular organs in causing SRR sickness was demonstrated by the fact that persons with bilateral labyrinthine defects were insusceptible, whereas normal subjects suddenly exposed to a terminal velocity of 10 rpm invariably experienced symptoms over prolonged periods while carrying out routine tasks (5, 8).

Three attempts to prevent symptoms by step increases to a terminal velocity of 10 rpm were unsuccessful (1); two involved three incremental steps over a period of approximately three days, and the third a series of 40 incremental steps over a period of 40 hours. The following report describes our first successful attempt. Overt symptoms of motion sickness were prevented solely by nine stepwise increases to a terminal velocity of 10 rpm over a period of 16 days, and the findings are discussed in terms of homeostatic mechanisms.

PROCEDURE

SUBJECTS

Four Navy enlisted men 17 to 19 years of age served as subjects. A comprehensive medical evaluation revealed no significant abnormalities. Details with regard to administration of the tests of their labyrinth function, which included ocular counterrolling (a test of otolith function), ataxia, threshold caloric, and evaluation of motion sickness susceptibility, have been described elsewhere (4,7,14,15,18).

THE SLOW ROTATION ROOM

The experiment was conducted in a circular windowless room 20 feet in diameter, 10 feet high, and without any central supporting members. It had a direct-motor drive capable of controlled angular accelerations between 0.1 and 15.0 deg/sec^2, with maintenance of angular velocities between 2 and 200 deg/sec within an accuracy of $\pm$ 1.0 per cent. The 10,000-pound payload was more than sufficient to provide for operation in the "housekeeping mode." The communication systems and bioinstrumentation facilities were not taxed in this experiment.

Subjects, when stationary with respect to the room rotating at constant velocity, were exposed to the vector sum of gravitational and centripetal forces; although aware of the inclination of the gravitoinertial vertical from that of the room, they were always comfortable when seated, and mentioned but did not complain of leaning in the direction of force when standing. Any motion of the subject resulted in a change in orientation with reference to the force environment and the generation of a Coriolis (third) acceleration. The Coriolis acceleration produced a force which was independent of the distance (radius) between the subject and the center of the room's rotation. The level of centripetal force changed if he moved to or from the center or with or against the direction of the room's rotation. The vector sum of all forces affecting the gravitoinertial upright stimulated the cilio-otolith system in the utricular and saccular maculae. The semicircular canals are so structured that the cupula-endolymph system was stimulated in an unusual manner by the Coriolis forces generated whenever the head was rotated out of the plane of the room's rotation (11).

GENERAL PLAN

Following three days of familiarization with the test program, the subjects entered the SRR where they remained for about 32 days; the rotation period was nearly 25 days. After four plus days of baseline tests, rotation was begun at 1930 hours of the fifth day; the room was accelerated in a counterclockwise direction to 2 rpm within a period of one minute. The evening of every second day thereafter the angular velocity was slowly increased by 1 rpm until a terminal velocity of 10 rpm was reached, where it remained for nearly nine days. At 1000 hours, on the morning of the 26th day, the room was brought to a standstill, but the subjects remained aboard for four days of postrotation tests.

Throughout the rotation period the room was stopped as necessary to allow experimenters and technicians ingress and egress. During these stops the subjects lay motionless along the radii of the room, with head inboard in order to prevent adaptation to a stationary environment. There were unscheduled stops on the twelfth and fourteenth rotation days due to power failure. There was some difficulty in temperature control; occasionally the room was either too warm or too cool, but only minor complaints were registered. The subjects remained on board the entire experimental period. The onboard experimenter (RD) was relieved each evening by a student flight surgeon.

TESTS AND METHODS

A wide variety of clinical, biochemical, and behavioral tests, similar to those used in a previous experiment, was carried out (8). Inasmuch as this report deals with motion sickness, only a few relevant procedures will be described.

The test schedule kept the subjects busy from morning till evening except at mealtime and during a mid-morning and mid-afternoon "break." They often worked in pairs, alternately taking and administering some of the tests. Each morning the subjects filled out a "pre-experiment questionnaire" dealing with their state of health. On three to five occasions during the day they filled out a "motion sickness questionnaire" with a section for the experimenter's comments. This was supplemented by a log kept by each subject and the onboard experimenter.

Certain tests were performed involving experimenter-paced head movements. On the fourth day of rotation at 10 rpm an attempt was made to determine susceptibility to SRR sickness when head movements were initiated with the subject recumbent and thus at right angles to the axis of rotation as would be the case in a rotating spacecraft. Following tape-recorded instruction, the subject was required to flex forward at the waist every five seconds until his trunk was upright; first, while rotating his head 90° to the left; second, while rotating 90° to the right; and third without head rotation. In this manner, 120 movements were made in ten minutes' time.

During the last five days of rotation, subjects C and D were "preconditioned" to a stationary environment by requiring them to move their heads while rotating clockwise in a Bárány-type chair. The resultant angular velocity was near zero with reference to the Earth, and the experimenter-paced movements, made every five seconds for ten minutes, consisted of leaning 45° leftward, rightward, and forward, after which the subjects filled out a motion sickness questionnaire.

Total urine output was collected from each subject during the entire experiment. The portion collected each day from 0800-1800 hours was designated the "day" sample and that collected from 1800-0800, the "night" sample. Excretion rates of the catechol amines, epinephrine and norepinephrine, and 17-hydroxycorticosteroids were determined in each sample by the methods of Crout (2) and Kornell (12), respectively. The sample volumes were measured after each collection period, stabilized at about pH 1 with HCl, and frozen until they were analyzed.

RESULTS

Without exception during the entire experimental period, all of the subjects indicated in the daily pretest questionnaire filled out each morning that they regarded themselves as in their usual state of health. The only medical problems were an unexplained gastrointestinal disturbance in subject C prior to rotation and an unsatisfactorily explained indisposition in subject A on the fifth day of rotation. Daily clinical evaluations by the onboard physician-experimenter, bolstered by routine hematological procedures, urinalysis, and other laboratory tests, revealed no definite variations from control values. Three subjects lost an average of 3 to 4 pounds, and subject B gained one pound during the period of rotation. The "chow" varied in its acceptability and may have been a factor.

The results of the analysis of the stress hormone excretion rates, Figure 1, revealed no significant differences from baseline rates throughout the entire experimental period. There were no significant interindividual differences in these values except for slightly less variance in those obtained in the tests of subject D.

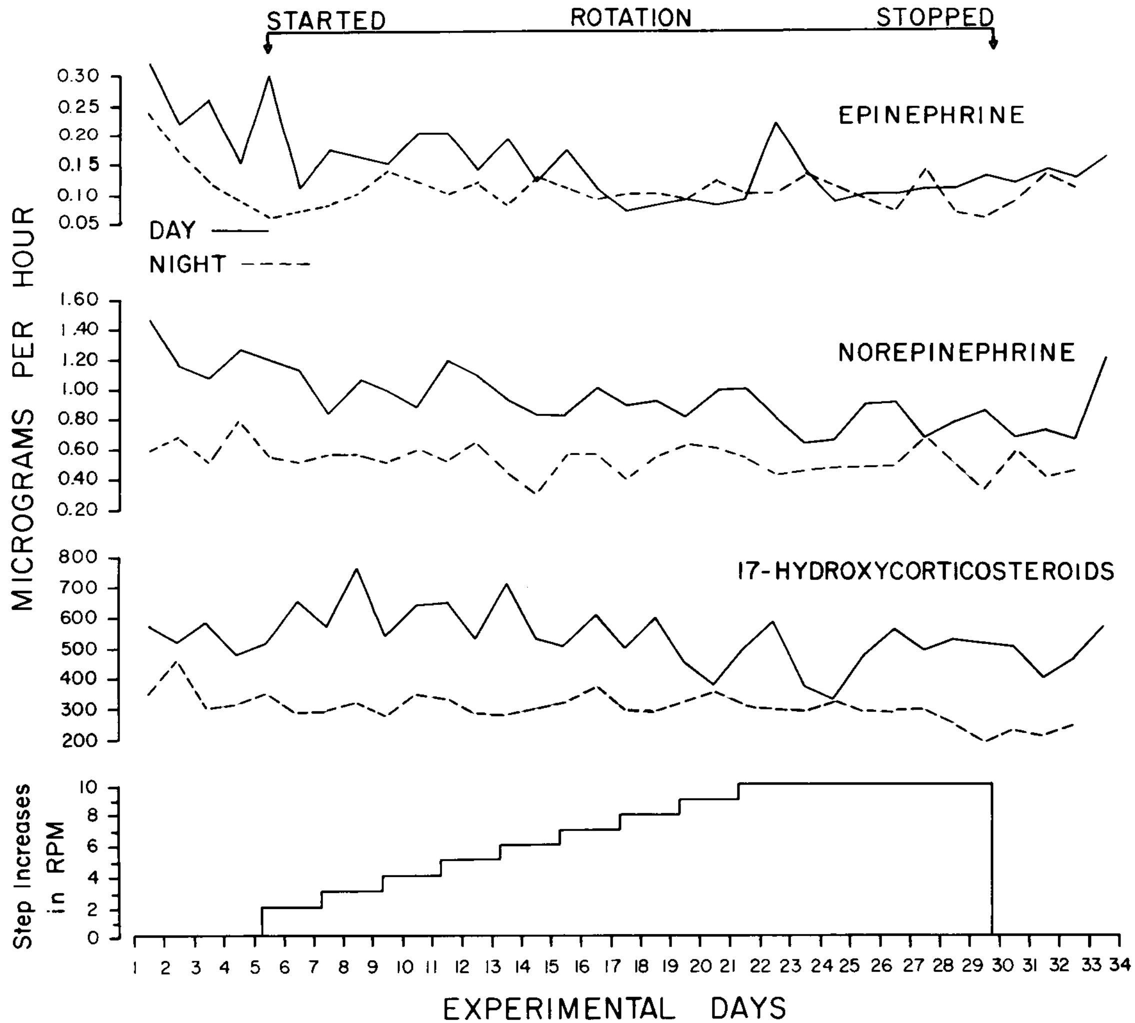

Figure 1

Mean Day and Night Excretion Rates of Catechol Amines and 17-Hydroxycorticosteroids in Four Normal Subjects Exposed in a Slow Rotation Room

The cardinal finding was the absence of the characteristic symptoms of motion sickness during rotation at constant velocity. None experienced symptoms with the onset of rotation at 1930 hours, although by then most of the day's activities were over. From that time until cessation of rotation, a kind of lethargy or drowsiness was a sometime complaint and was clearly evident to the onboard experimenter. There was a tendency for the subjects to nap during the day, and this was reflected in the reduced hours of sleep at night. On cessation of rotation, ataxia was the most prominent and lasting complaint, and symptoms of motion sickness were either absent or of small significance. There were interindividual differences in the subjects, and various episodes occurred through the month-long experiment which are best described on an individual basis.

SUBJECT A

The onboard experimenter regarded subject A as the natural leader of the group and the most dependable. His main complaint on the questionnaires was bad chow whenever it was cold, soggy, or unappetizing. He also mentioned on some occasions but did not complain of a poor job when blood was drawn. He acquired the habit, as did the others, of napping in the daytime but, unlike the others, was not sleepy at lights out. With the exception of a few occasions, he was always cheerful and feeling good.

Although he indicated slight drowsiness on the questionnaire completed at 1100 hours on the morning of the second perrotation day, he reported no ill feelings at all in his log. At 0700 on the morning of the fifth perrotation day, after rotating at constant velocity for over 36 hours, he stated that he felt good. An hour later after the blood test he complained of slight headache, slight dizziness, and no appetite. That evening after the increase to 4 rpm he began to feel better, and his appetite returned. The negative relationships between onset or disappearance of symptoms and change in angular velocity suggest that Coriolis accelerations were either noncontributory, or at most, a secondary factor. On the twelfth perrotation day (7 rpm) at the time of an unscheduled stop, he was moving about and stated that he felt dizzy when he moved his head, warm, had a slight headache, and lost appetite. He was told to remain still, and 30 minutes after the room was again at constant velocity, he felt good. He entered comments in the log on most occasions when the angular velocity of the room was increased; the following are typical ones: "do not notice change except in walking"; "no discomforts." On receiving the news that the period of rotation was at an end he wrote, "It was all a big shock to us. We thought he (onboard experimenter) was kidding." After cessation of rotation he wrote, "Was hard to walk. My head felt dizzy as if I was drunk - hands were sweaty and damp. I felt very excited as if going on a trip. Did not eat much although I was hungry."

SUBJECT B

Many comments were logged by this subject, some amplifying the information in the questionnaire. Three days prior to rotation he took aspirin for headache, the following day he cut his finger, and the day prior to rotation he "had a little argument with subject D." These findings are important in demonstrating that incidents may occur in the absence of stressful accelerations. The evening of the fourth perrotation day he felt tired, and after breakfast on the sixth day he had slight stomach discomfort and no appetite for the noon meal. He sometimes wrote, "ordinary day" or "same as other days," but usually a statement to the effect that he felt well. He amplified this on the seventeenth perrotation day by writing, "So far we are not bored or hot tempered." The onboard experimenter, however, noted some wrangling but nothing serious. Cessation of rotation came as a surprise; he wrote, "It made me feel a little uneasy like a kid with a new toy - sort of anxious - I felt a little nausea at first." His only persistent postrotation complaints were dizziness and instability when walking. His final comment: "It was a great experience, would do it again."

SUBJECT C

The day prior to the onset of rotation subject C experienced a gastrointestinal disturbance characterized by abdominal cramps, diarrhea, and vomiting. By next morning he had improved, and in view of the low level of stress and of his own strong desire, he was retained as one of the subjects. Later in the day he again experienced slight abdominal "cramps" which disappeared prior to the onset of rotation. This subject confined his comments in the log mainly to a listing of the day's activities. He seemed to be the least affected of all by the Coriolis accelerations and except for ataxia had no complaints on cessation of rotation. On the sixth perrotation day he wrote, "Everybody in high spirits as usual"; on the ninth, "had two aspirins"; on the third day after reaching 10 rpm, "everything went as usual"; and on the day before cessation of rotation, "all of us feel great." He was one of the subjects scheduled for preconditioning to the stationary environment before cessation of rotation, which might have been a factor in his having no postrotation symptoms of SRR sickness.

SUBJECT D

The onboard experimenter regarded this subject as the one who "sacked out" far more than the other subjects and was given to "needling" others on board; his report contrasts sharply with some of the comments in this subject's log. With the onset of rotation the subject wrote, "funny feeling in head like dizziness but otherwise feeling fine." He felt tired on the morning of the third perrotation day and a little dizzy when the room increased velocity to 3 rpm. Thereafter, he stated that he felt fine or great on all but two of the remaining perrotation days; one day there was no comment in the log, and on the other he had an argument with the student flight surgeon. On one of the days he felt fine he wrote, "another bossy (student) flight surgeon, took two aspirin." He was one of the subjects who took preconditioning exercises prior to cessation of rotation, and, aside from slight headache and ataxia, experienced no symptoms on cessation of rotation.

ONBOARD EXPERIMENTER

Comments by the experimenter fell into three categories, namely, those pertaining to the subjects, to himself, and to the flight surgeons who relieved him at night.

Commenting on the subjects the day prior to the onset of rotation, he wrote, "Slight very early signs of some effects from the three plus days here" (confinement); next morning, "chow this a. m. not as good as before - almost no one ate"; and that evening, "rotating without fuss - doing well." The morning of the first full day of rotation he wrote, "Boys definitely tired this a. m.; after work period everybody, including me, sacked out." The morning of the second day, he wrote, "Fellows less sleepy today"; the morning of the fourth day, "hard to get men up and working"; the afternoon of the sixth day, "boys fine." Thereafter, there were fewer comments regarding lethargy on the part of the subjects except in the case of subject D who continued to "sack out" at every opportunity. There was a moderate amount of friction between two of the subjects, according to the experimenter, but there was only a hint of this in the logs of the subjects involved.

The onboard experimenter's comments regarding his own symptoms are of particular interest inasmuch as after the first 24 hours aboard, he alternated between a rotating and stable environment. His comments should be viewed in light of the fact that he was more susceptible than average to SRR sickness.

The evening rotation began, he experienced stomach awareness but arose, after a restful night, feeling well. At 1100 hours he wrote, "Believe slight adaptation has occurred in me. Have sensation of slight hypnotic drug wearing off." On leaving the SRR he experienced slight ataxia and slight nausea and required about three hours to adapt fully to the stable environment. After re-entering the SRR the next morning he soon felt tired but seemed to adapt more easily. After the work period he slept 30 minutes, waking spontaneously. On leaving the SRR he wrote, "Somewhat more trouble in readapting to Earth but not too tired."

On the third day the experimenter wrote, "I adapted to 3 rpm as easily as to 2 rpm yesterday. Move freely about, no restrictions (head movements)." On the fourth day (3 rpm) he adapted rapidly. On leaving the SRR he had more disequilibrium but readapted in two to three hours and had no symptoms of fatigue. On the fifth day (4 rpm) he experienced stomach awareness at first, which disappeared, and had no restrictions of movements. On leaving the SRR he kept fairly quiet, had stomach awareness, and did not fully adapt with respect to postural equilibrium.

The SRR was rotating at 5 rpm on the sixth day, and the onboard experimenter wrote that he "finally adapted by about 1400 hours - no oculogyral (Coriolis) illusion." On leaving the SRR he was very unsteady and experienced slight malaise. That evening he took the FAA written test for a private pilot's license and reported very fuzzy thinking. The next morning he took d-amphetamine 10 mg and hyoscine 0.6 mg before entering the SRR (5 rpm) and reported no significant malaise. At 1530 hours he took one-half the morning dose of medicine and later wrote, "Had no symptoms today." The same routine was followed on the eighth day with the SRR at 6 rpm, and he reported "not tired -- no motion sickness," and ataxia was the only symptom on leaving the SRR.

On the ninth day the experimenter reported, "No problem"; on the tenth (7 rpm), "things went well"; and on the eleventh, "I still feel fine with about 1-2 hours lag till I readapt either to wheel or Earth; no motion sickness or malaise." His next report concerning symptoms was on the sixteenth day with the room rotating at 10 rpm. He wrote, "No one had significant motion sickness so far; have some stomach awareness this afternoon about one hour after taking my medicine -- not really a vestibular motion sickness -- more like a gastric irritant." On the second day at 10 rpm he wrote, "We have already proven first goal, i.e., can we get a group gradually to 10 rpm without symptoms of motion sickness; we can and did. Feel strongly an isolation type control experiment should be done sometime." Thereafter his comments dealt mainly with a critique of the experimental design and the subjects who seemed tired and lethargic even after rotation ceased.

The onboard experimenter's comments regarding the student flight surgeons' experiences while on night duty included the fact that their minimal duties enabled them to restrict their movements and thus avoid or reduce the stressful accelerations. In general, they experienced mild symptoms of motion sickness at slow rates of rotation, and at 5 rpm they began taking amphetamine (10 mg) and hyoscine (0.6 mg) one hour before boarding. This sufficed until 9 rpm was reached, after which supplemental medication was taken but did not always prevent vomiting.

Two weeks after the period of confinement was over the subjects were again subjected to rotation at 10 rpm. Rotation in the counterclockwise (same) direction resulted in mild symptoms, but rotation in a clockwise direction was not well tolerated. Much the same difference in symptoms was manifested by two observers onboard at the time who were also accustomed to rotation in the counterclockwise direction.

DISCUSSION

The findings in this experiment will be discussed first in general terms, then with regard to certain theoretical and practical implications.

GENERAL

One important question is whether the subjects in the present experiment experienced symptoms of motion sickness during rotation at constant velocity.

Aside from specific episodes to be considered later, drowsiness, broadly defined to include lethargy, was the only symptom which may have had its genesis in the effects of Coriolis acceleration on the vestibular organs. Here the diagnosis is complicated by the nonspecificity of drowsiness and the fact that it is a common complaint under conditions of spatial confinement such as in the present experiment. In the early portion of the rotation period the findings indicate that drowsiness was maximal on the second and third days of rotation and then tapered off, suggesting that the force environment was of etiological significance. The absence of drowsiness between the onset of rotation at 1930 hours and lights out that night might be explained by the excitement of a new experience and the fact that the day's activities were nearly completed.

It would seem reasonable to believe that the effects of confinement would increase gradually with time and tend to persist, and it is difficult to believe that rotation during the final few days at 10 rpm generated stressful Coriolis accelerations except in conjunction with bodily movements of the subjects as required for special tests. Although it is venturesome to ascribe a single symptom to "motion" unless the relationship is definite and other etiologic factors are absent, confinement and the force environment each probably contributed to drowsiness in the present experiment. If it is assumed that Coriolis accelerations were of etiologic significance, then the findings suggest that drowsiness may be experienced during prolonged exposure to Coriolis accelerations at levels insufficient to evoke the nausea syndrome and other cardinal manifestations of motion sickness. In a previous study involving subjects suddenly exposed to 10 rpm for a period of 12 days (8), drowsiness and fatigue were prominent complaints long after all evidence of the nausea syndrome had disappeared, indicating different time-courses for nausea and drowsiness. In our attempt to define different levels of severity of acute SRR sickness based on brief exposure to graded Coriolis accelerations, early symptoms of the nausea syndrome were nearly always experienced by the subject before a reliable endpoint was reached (7). The rare exceptions were persons who manifested usually a single symptom to a striking degree before there was any evidence of the nausea syndrome. Drowsiness occurred in only a small percentage of subjects who were relatively insusceptible, thus requiring a longer than average period of exposure to stress. A striking instance was that of a subject who actually fell asleep while making head movements in response to taped instructions.

Incidents such as that when subject A experienced mild symptoms on the fifth rotation day after blood was drawn and again on the twelfth day while the room was coasting to an unscheduled stop, might be explained by reduced reserve, in terms of susceptibility to SRR sickness, predisposing him to the effects of secondary factors of etiologic importance.

On cessation of rotation the mild symptoms experienced by three subjects should be attributed to the change in the force environment because of the close temporal relationship. Only the nausea experienced by the one subject, however, reached the minimal symptom level qualifying as a reliable endpoint for diagnostic purposes based on our experience (7). Although somewhat more severe postrotation symptoms were expected, our past experience has indicated there is great individual variance and has suggested that postrotation symptoms are more severe after brief than after prolonged exposure.

THEORETICAL IMPLICATIONS

Certain implications can be drawn when the results in this experiment are considered along with the cardinal findings in two previous similar experiments; namely, normal subjects invariably became sick and persons with loss of vestibular function invariably did not.

The fact that adaptation to strong Coriolis accelerations can occur in the absence of overt symptoms is clear proof that the adaptive processes differ either qualitatively or quantitatively from the neural processes involved when symptoms occur. Clearly, the adaptive processes prevented or at least inhibited the irradiation of vestibular activity to cerebellar, hypothalamic, and other cell assemblies involved in the genesis of symptoms when normal persons were exposed to an initial velocity of 10 rpm. Moreover, the findings in the present experiment proved that "adaptation or habituation of symptoms" was not essential to the adaptation process. These processes, ensuring man's stability at 10 rpm, must be regarded as true homeostatic processes ensuring a homeostatic state.

The possibility that homeostasis might have been achieved through a feed-back mechanism via the efferent vestibular pathways suppressing the signals from the peripheral organs deserves consideration and has been suggested (13) as a mechanism responsible for the abolition of motion sickness symptoms. In favor of this explanation is the simplicity of a general suppressing mechanism and the fact that the abrupt change in the force environment on cessation of rotation evoked minimal or no symptoms of motion sickness. The incidental observations demonstrating susceptibility to symptoms when exposed to clockwise rotation after adapting to counterclockwise rotation would, however, argue against a single general mechanism; so would the fact that adaptation to a specific force environment fails to ensure the prevention of symptoms in other force environments.

An alternative or additional explanation would involve changes at cell stations along normal or usual vestibular pathways. Starr and Livingston (16), using electrophysiological recording techniques, demonstrated changes in cell stations along the auditory pathway in cats exposed to intense prolonged noise, and Galin (3) demonstrated changes in activity at such cell stations in response to a conditioning stimulus. Whatever the mechanism in our subjects, it was triggered by small increments in Coriolis accelerations, each adding to the final level of adaptation which sufficed to prevent the characteristic syndrome of motion sickness at 10 rpm. The process of adaptation clearly inhibited the irradiation of vestibular activity to areas concerned in the genesis of primary symptoms of motion sickness.

Groen (9) postulated that the adaptation is central in origin where a "copy or image" of the stimulus pattern is gradually built up which "counteracts the penetration of the signals into the higher nuclei."

Wendt (17) proposed that habituation of nystagmus might be the result of a "competing eye movement system," and, indeed, something of this nature may have resulted in regard to habituation of the Coriolis oculogyral illusion (6) and Coriolis nystagmus (10), phenomena regularly associated with SRR sickness. Both phenomena undergo a response decline as a function of continued exposure in the SRR and, following cessation of rotation, both are evoked by appropriate head movements but opposite in sense to that initially experienced in the rotating room. Motion sickness in the slow rotation room represents a failure in homeostatic processes resulting primarily from a too sudden exposure to Coriolis accelerations in susceptible persons. The symptoms are evoked by an effective irradiation of abnormally patterned vestibular inputs to areas either not normally stimulated or stimulated ineffectively. The symptoms represent absurd responses in terms of the welfare of the subject and clearly involve nonhomeostatic processes resulting in a nonhomeostatic state. Whether a second adaptive process involving the nonhomeostatic mechanisms contributes to the abolition is a possibility.

PRACTICAL IMPLICATIONS

The findings in this experiment have important practical implications if a decision is made to rotate a spacecraft to generate artificial gravity in space flight. This applies both to habituation of astronauts in a rotating environment prior to launch and optimal incremental increases in rotational velocity of the spacecraft aloft.

The findings in this experiment are probably applicable also to motion sickness in other force environments. Indeed, there is nothing new in the concept of preventing motion sickness by gradual exposure to stressful accelerations.

REFERENCES

1. Bergstedt, M., Stepwise adaptation to a velocity of 10 rpm in the Pensacola Slow Rotation Room. In: The Role of the Vestibular Organs in the Exploration of Space. NASA SP-77. Washington, D. C.: U. S. Government Printing Office, 1965. Pp. 339-344.

2. Crout, J. R., Catechol amines in urine. In: Seligson, D. (Ed.), Standard Methods of Clinical Chemistry, Vol. 3. New York: Academic Press, 1961. Pp. 62-80.

3. Galin, D., Effects of conditioning on auditory signals. In: Field, W. S., and Alford, B. R. (Eds.), Neurological Aspects of Auditory and Vestibular Disorders. Springfield, Ill.: Charles C Thomas, 1964. Pp. 61-75.

4. Graybiel, A., and Fregly, A. R., A new quantitative ataxia test battery. Acta otolaryng., Stockh., 61:292-312, 1966.

5. Graybiel, A., Clark, B., and Zarriello, J. J., Observations on human subjects living in a "slow rotation room" for periods of two days. Arch. Neurol., 3: 55-73, 1960.

6. Graybiel, A., Guedry, F. E., Jr., Johnson, W. H., and Kennedy, R. S., Adaptation to bizarre stimulation of the semicircular canals as indicated by the oculogyral illusion. Aerospace Med., 32:321-327, 1961.

7. Graybiel, A., Wood, C. D., Miller, E. F., II, and Cramer, D. B., Diagnostic criteria for grading the severity of acute motion sickness. Aerospace Med., 39:453-455, 1968.

8. Graybiel, A., Kennedy, R. S., Knoblock, E. C., Guedry, F. E., Jr., Mertz, W., McLeod, M. E., Colehour, J. K., Miller, E. F., II, and Fregly, A. R., The effects of exposure to a rotating environment (10 rpm) on four aviators for a period of twelve days. Aerospace Med., 36:733-754, 1965.

9. Groen, J. J., Adaptation. Pract. oto-rhino-laryng., 19:524-530, 1957.

10. Guedry, F. E., Jr., and Graybiel, A., Compensatory nystagmus conditioned during adaptation to living in a rotating room. J. appl. Physiol., 17:398-404, 1962.

11. Guedry, F. E., and Montague, E. K., Quantitative evaluation of the vestibular Coriolis reaction. Aerospace Med., 32:487-500, 1961.

12. Kornell, L., An improved, rapid method for free and conjugated 17-hydrocorticosteroids in urine. Metabolism, 8:432-440, 1959.

13. McCabe, B. F., and Gillingham, K., The mechanism of vestibular suppression. Trans. Amer. Otol. Soc., 52:226-238, 1964.

14. McLeod, M. E., and Meek, J. C., A threshold caloric test: Results in normal subjects. NSAM-834. NASA Order R-47. Pensacola, Fla.: Naval School of Aviation Medicine, 1962.

15. Miller, E. F., II, Counterrolling of the human eyes produced by head tilt with respect to gravity. Acta otolaryng., Stockh., 54:479-501, 1962.

16. Starr, A., and Livingston, R. G., Long-lasting nervous system responses to prolonged sound stimulation in waking cats. J. Neurophysiol., 26:416-431, 1963.

17. Wendt, G. R., The nature of adaptation to oscillatory rotation. In: The Role of the Vestibular Organs in the Exploration of Space. NASA SP-77. Washington, D. C.: U. S. Government Printing Office, 1965. Pp. 133-139.

18. Woellner, R. C., and Graybiel, A., Counterrolling of the eyes and its dependence on the magnitude of gravitational or inertial force acting laterally on the body. J. appl. Physiol., 14:632-635, 1959.

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13. ABSTRACT

Four Navy enlisted men were exposed in a slow rotation room (SRR) by stepwise increases over a period of 16 days to a terminal velocity of 10 rpm. The fact that overt symptoms of motion sickness at 10 rpm were prevented solely by the incremental increases demonstrated that adaptive processes somehow inhibited irradiation of vestibular activity to cell assemblies in areas concerned in the genesis of symptoms. The SRR sickness observed in other subjects suddenly exposed to 10 rpm thus may result from failure of homeostatic processes, permitting such irradiation. The underlying processes therefore are clearly nonhomeostatic in nature and produce a nonhomeostatic state. The findings in the present experiment have practical as well as theoretical implications.

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